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the result is

$$\alpha\Delta\theta' = \frac{A - B/y}{1 + Cy} \tag{9}$$

Here y is the ratio of solid and liquid sections and we inquire what value of y will make $\Delta\theta'$ a maximum provided A, B, C are constant. If the thermal and elastic elongations are to be equal $A = 2B$. Differentiating (9) and reducing:

$$1/y = C(\sqrt{1 + A/BC} - 1) \tag{10}$$

and since y must be positive the radical is positive. Now if $A = 2B$, for example, the ratio of diameters $2r_1$ to $2r_2$ would in all cases have to exceed 0.65. If $A = 3B$, the case of water remains nearly the same, but for ether and alcohol the diameter ratio approaches 0.9.

[1] These PROCEEDINGS, 5, 1919, (267–272).
[2] Carnegie Publ. No. 249, 1917, pp. 84–94.

STUDIES OF MAGNITUDES IN STAR CLUSTERS, IX. THE DISTANCES AND DISTRIBUTION OF SEVENTY OPEN CLUSTERS

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The question of whether globular clusters are really or only apparently absent from the mid-galactic segment makes the study of the distances of open clusters particularly important. These objects are relatively near to the galactic circle, and many appear to be at such great distances along the plane as to support the hypothesis that obstructing matter is insufficient to occlude globular clusters in mid-galactic regions.[1] On the other hand there is evidence that globular clusters actually may not be absent from low galactic latitude,[2] and the following discussion of open clusters and other relevant factors suggests that the question must be considered an unsettled one for the time being.

Although the question of the reality of the region of avoidance affects but little the general conclusions reached in earlier papers regarding globular clusters, spiral nebulae, and the Galaxy, two modifications should be made to previously suggested interpretations,[3] in case we demonstrate the existence of much obstructing matter along the galactic

plane beyond the confines of the local cluster: First, the distance of the center of the system and the total extent of the Galaxy may be considerably greater than inferred from the visible globular clusters; second, the transition from globular to open clusters, if there be such an evolution,[4] is not necessarily rapid and inevitable when the globular clusters enter thickly populated galactic regions.[5] It should be noted that the diameter-parallax correlations[6] are some insurance that a hypothetical *partial* obstruction has exaggerated neither the distances of globular clusters nor the galactic dimensions. If dark clouds obscure distant globular clusters they are remarkably thorough (except in one or two possible cases[7]), the obscuration at any point appearing to be absolute or non-existent. According to the magnitude results now available for faint galactic stars, the obstructing clouds also are of such character that they do not affect star colors appreciably.

Several years ago the correlation of the apparent diameter to the brightness of stars in open clusters was pointed out and the possibility noted of obtaining relative parallaxes from measures of magnitude or diameter.[8] My values of the relative parallaxes of these open groups, however, as well as the provisional absolute values, have remained unpublished in the hope that the accumulation of data on magnitudes and spectra would permit the determination of more definite absolute parallaxes. The open clusters contain few, if any, Cepheid variables, and appear almost without exception to be quite beyond the reach of direct measures of distance. Parallaxes of an accuracy comparable with that for globular clusters seem unattainable; but, notwithstanding some uncertainty in diameters due to looseness of structure and to intermixture with the Milky Way stars among which the open clusters usually lie, it appears quite possible to use their angular dimensions to determine a system of relative distances and to use the apparent magnitudes of the red giants or the B-type stars in as many clusters as possible to establish the scale and zero point for absolute distances.

My observational work on open clusters comprises: (1) Thirty spectrograms of some 200 faint stars in various northern groups, made with a slitless spectrograph of small dispersion at the 80-foot focus of the 60-inch reflector; (2) more than a hundred direct photographs at the primary focus of the 60-inch; (3) the determination of magnitudes and colors of about two thousand stars; (4) the measurement of the diameters and form of all known open clusters on Franklin-Adams charts, Harvard photographs, or Mount Wilson plates. This work has been supplemented by similar data from other sources, chiefly from the

observations at Harvard on the spectra in a few bright clusters[9] and from the work of Adams and van Maanen on the double cluster in Perseus.[10]

The accompanying table contains the parallaxes and space coördinates of the 70 open groups which are sufficiently rich, condensed, symmetrical, and distinct from the background to make practicable the use of diameter as a criterion of distance. Melotte's well-known catalogue[11] of clusters contains more than twice as many open groups as are listed here, but a large number of his clusters are so ill-defined and poor in numbers that they appear to be little else than chance groupings of Milky Way stars. The omission of these irregular and scattered aggregations does not operate selectively in matters of distance or distribution.

The first column of the table contains the number of the cluster in Dreyer's *New General Catalogue* or its indices. A few that are not listed by Dreyer retain their numbers in Melotte's catalogue. Parallaxes of the fourteen clusters marked with an asterisk have been derived directly from measured apparent magnitudes combined with absolute magnitudes estimated on the basis of observed colors, or spectra, or both. The adopted mean absolute magnitudes of early type stars depend on the studies of Kapteyn,[12] Plummer,[13] and Charlier,[14] and on my own results for the luminosities of blue stars in globular clusters. Apparently without exception the brightest stars in open clusters (as in globular clusters) are giants in luminosity.

By using the measured diameters and adopted distances of these specially studied clusters to determine a parallax-diameter curve, the parallaxes of the other open clusters have been estimated on the basis of diameters alone; in most cases, however, the relative distances have been roughly checked with the aid of the magnitudes of the brightest stars as estimated by Bailey[15] or as derived from Mount Wilson photographs. The diameters are the means of measures by Bailey, Melotte, Shapley, and Miss Davis. In keeping with the probable accuracy, most of the parallaxes have been rounded off to a single significant figure after computing the linear galactic coördinates, which are given in the fourth and fifth columns. The very largest parallaxes are uncertain because of the lack of precision in the corresponding end of the parallax-diameter curve; the very smallest are uncertain because of the large effect of small errors in measurement of diameter; most of the diameters, however, fall within limits for which the curve is well-defined and for which the measures of diameter by the four observers are

in good agreement. It is expected that the measures and computations underlying this work and a more complete discussion will appear in a *Mount Wilson Contribution.*

POSITIONS IN SPACE OF SEVENTY OPEN CLUSTERS

N. G. C.	GALACTIC LONGITUDE	PARALLAX	DISTANCE (UNIT 100 PARSECS		N. G. C.	GALACTIC LONGITUDE	PARALLAX	DISTANCE (UNIT 100 PARSECS	
			Along plane	From plane				Along plane	From plane
457	93°	0.00016	62	− 5.3	2682*	183°	0.00025	34	+22.0
663	97	0.0002	50	− 1.2	I. C. 2488	245	0.0002 :	43	− 2.7
869*	102	0.0008	12	− 0.9	3114	250	0.001:	10	− 0.5
884*	103	0.0008	12	− 0.8	3532†	257	0.002:	4	+ 0.1
1039	111	0.0006	17	− 5.0	I. C. 2714	259	0.0002	59	− 1.2
1245	114	0.0002	44	− 7.1	Mel 105	260	0.00007	140	− 4.7
Pleiades*	134	0.015	0.6	− 0.3	Mel 108	262	0.0001	90	+10.5
1528	119	0.0004	24	0.0	4349	267	0.00025	40	+ 1.0
1807	154	0.0002	42	− 9.7	5281	277	0.00007	140	− 0.4
1912*	139	0.0003	32	+ 0.6	5617	282	0.0002	50	+ 0.2
1960*	142	0.0002	48	+ 1.1	5823	289	0.00015	67	+ 3.3
2099*	145	0.0004	26	+ 1.5	5999	293	0.0001	100	− 3.5
2168*	154	0.0006 :	18	+ 0.8	6005	293	0.00006	160	− 9.2
2266	154	0.00009	110	+20.0	6067	297	0.0002	45	− 1.7
2287	199	0.0006 :	16	− 2.6	6124	308	0.0005	21	+ 2.2
2323*	189	0.0002	50	− 0.4	6134	302	0.00014	71	− 0.1
2324	181	0.0001	91	+ 6.4	6192	308	0.0001	83	+ 3.2
2355	170	0.0001	98	+22.0	6222	309	0.00007	140	− 0.4
2360	197	0.00014	71	− 0.8	6242	313	0.00014	71	+ 2.8
2421	204	0.0001	77	+ 1.2	6259	310	0.0002	53	− 1.5
2420	165	0.0001	94	+34.0	I. C. 4651	308	0.0002	50	− 7.0
2423	199	0.0003	34	+ 2.7	6405*	324	0.001:	8	− 0.1
Mel 71	197	0.0001	77	+ 7.8	6451	327	0.00009	110	− 3.9
2439	214	0.0001	91	− 5.7	6475*	323	0.003:	4	− 0.3
2437	200	0.0005	21	+ 1.8	6494	338	0.0005	21	+ 0.8
2447	208	0.0002	43	+ 1.0	6520	330	0.00009	110	− 6.2
2477	221	0.0005	20	− 1.8	6603	340	0.00008	120	− 3.8
2489	214	0.0001	100	+ 0.3	Mel 204	341	0.0006 :	16	− 1.5
2506	198	0.0001	98	+19.0	6645	343	0.0002	56	− 4.2
2516	241	0.002:	6	− 1.5	6705*	355	0.00014	71	− 4.2
2539	201	0.0003	31	+ 6.8	6709	10	0.0002	56	+ 3.8
2548	195	0.0007:	14	+ 4.2	6834	33	0.00008	120	+ 0.9
2567	217	0.0001	83	+ 5.5	6838*	24	0.00007	140	−14.0
2627	219	0.0001	90	+12.0	7654	80	0.00016	62	− 0.2
2632*	172	0.003:	25	+ 1.6	7789	83	0.0003	37	− 3.7

† The bright southern cluster N.G.C. 3532 is conspicuously elliptical.

The well-known concentration of open clusters in the Milky Way is shown by the smallness of the tabular distances from the plane. This condition allows a good representation of the distribution in space

simply through plotting (as in figure 1) the galactic longitude and the distance projected on the galactic plane. No striking lack of symmetry appears in this diagram, except the almost total absence of bright open clusters in the first 90° of galactic longitude.

The mean distance of the 70 open clusters along the plane is 5900 parsecs, all individual values (except for the Pleiades) lying between 400 and 16,000 parsecs. By taking the dip of the central line of the Milky Way[16] as 1°, and the distance of the sun above the plane as 60 parsecs,[17] the distance of the stars and star clouds that enter Newcomb's

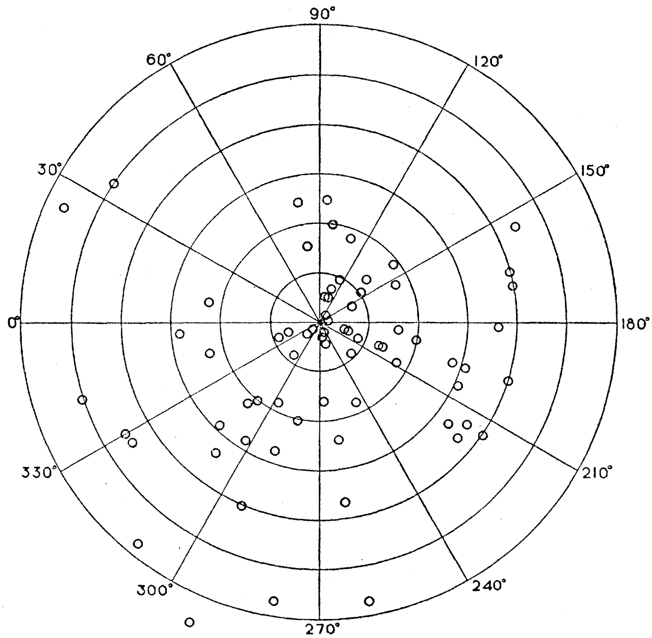

FIG. 1. DISTRIBUTION OF OPEN CLUSTERS IN THE GALACTIC PLANE
The direction angles are galactic longitudes; the annuli are 25,000 parsecs in width

(visual) determination of the position of the galactic circle is of the order of $60/\sin 1° = 3500$ parsecs. Although the uncertainty of this value is large, it seems reasonable to infer that the open clusters are intermingled with the non-cluster stars of the galactic stratum.

The diagram in figure 2 illustrates, for all the open clusters, globular clusters, and Cepheid variables falling between galactic longitudes 290° and 360°, the distances projected on the galactic plane plotted as abscissae against the distances from the plane as ordinates. This region of the sky, containing the great Milky Way clouds of Ophiuchus,

Sagittarius, and Scorpio, is symmetrical about the point that is indicated by the distribution of globular clusters as the center of the galactic system. It is mainly the absence of globular clusters from low galactic latitudes throughout this interval of 70° in longitude that gives rise to the phenomenon of a region of avoidance. The diagram shows that the distribution of stellar material is probably fairly continuous along the galactic plane; from the local cluster the Cepheid variables (and various other types of highly luminous galactic stars) extend to the nearer star clouds and open clusters, and the latter are recorded among the more distant star clouds along the plane nearly as far as the center of the system of globular clusters.

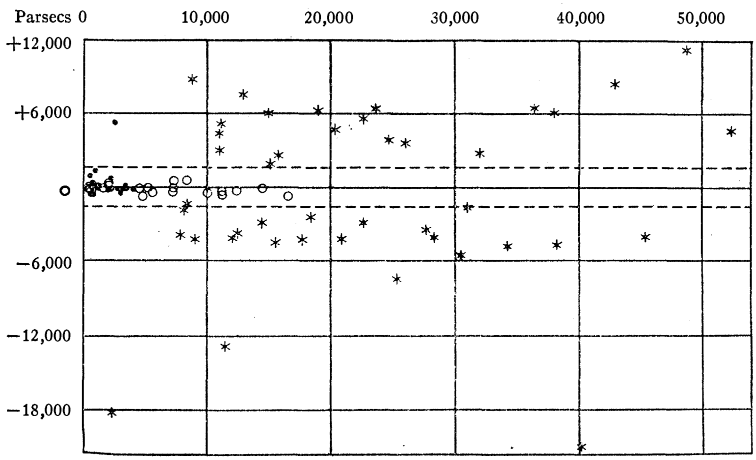

FIG. 2. DISTRIBUTION OF THE GLOBULAR CLUSTERS (ASTERISKS), OPEN CLUSTERS (OPEN CIRCLES), AND CEPHEID VARIABLES (DOTS) THAT FALL BETWEEN GALACTIC LONGITUDE 290° AND 360°

Ordinates are distances from the galactic plane; abscissae are distances along the plane

If, as appears very probable, the system of globular clusters outlines the galactic system, why do we not find large numbers of open clusters in the vicinity of and beyond the center, between the two halves of the assemblage of globular clusters? Nearer the sun there are some 70 open groups within the mid-galactic segment—the segment which appears to be their natural and only domain. Is the distant central region that is devoid of globular clusters also in part avoided either actually or apparently by open clusters? The observed scarcity of open clusters in this direction leads us to question the reality of the avoidance; it may be that patches of obscuring material conceal both open and globular clusters, as well as many of the more distant stars,

perhaps thus playing a large part in the conspicuous rifts in the Milky Way.

Barnard's dark markings, recently catalogued,[18] do not furnish direct evidence of this obscuration, for, singularly enough, more than half of his objects fall outside the region of avoidance, if we exclude one small region near Messier 11 for which 30 separate positions are listed. It appears that most of the markings may be affiliated with the local cluster, and at no great distance from the sun. Thus in the Taurus-Orion region, two-thirds of the dark markings have negative galactic latitudes, lying on the average more than 10° south of the galactic circle; in the opposite region the latitudes are largely positive, the dark markings in Ophiuchus and Scorpio lying intermingled with the seemingly unaffected globular clusters. Along the middle line of the region of avoidance relatively few markings are recorded.

Indirectly, however, in Barnard's nebulae we have an argument favoring the hypothesis that globular clusters are concealed in mid-galactic regions, for, if a considerable amount of obscuration is associated with the relatively small local cluster, it suggests that such material may also be common in other stellar regions. Although the star counts in typical open and globular clusters fail to reveal as yet the presence of such obscuration, the distribution of stars in the Magellanic Clouds suggests the possibility of its presence there.

Another point of considerable weight against a real absence of globular clusters from the region of avoidance is the difficulty and improbability of such a dynamical condition. The distribution of globular clusters in space shows their very close relationship to the Galaxy; the average velocity and probable mass both appear to be very great; the possibility, therefore, of repelling a globular cluster from the stellar stratum, or completely transforming it during a single passage, seems remote. From a gravitational standpoint we should naturally expect the frequency of clusters to be greatest at or near the galactic plane, and that many oscillations must occur before the hypothetical assimilation and transformation is completed for an average globular cluster.

Of the several arguments favoring the reality of the empty zone, we recall that the most important are the completeness of the observed absence at all distances from the sun, and the various suggestions of immediate genetic relationship between the external globular clusters and the open clusters within, including the observation that the globular clusters nearest the plane appear to be the most open.

[1] Shapley, Harlow, *Mt. Wilson Contr.*, No. 152, 1917 (1–28), pp. 22, 23 and footnotes; No. 157, 1918 (1–26), p. 10; No. 161, 1918 (1–35), sections I, II, and III.

[2] *Ibid.*, No. 157, 1918 (1–26), p. 12; No. 161, 1918 (1–35), section IV.

[3] *Ibid.*, No. 157, 1918 (1–26); No. 161, 1918 (1–35), sections VII and VIII.

[4] *Ibid.*, No. 161, 1918 (1–35), section VIII; No. 157, 1918 (1–26), pp. 12–14.

[5] But whether the absence of clusters is real or only apparent, we must remember that the assignment of a definite thickness of three or four thousand parsecs to the galactic segment is mostly a matter of convenience and approximation; the intention is merely to suggest that practically every known object except spiral nebulae and globular clusters is within a thousand parsecs or so of the central plane of a greatly extended, indefinitely bounded stellar stratum.

[6] Shapley, Harlow, *Mt. Wilson Contr.*, No. 152, 1917 (1–28), fig. 1; No. 161, 1918 (1–35), section V.

[7] *Ibid.*, No. 152, 1917 (1–28), p. 22, footnote 2.

[8] *Ibid.*, No. 115, 1915 (1–21), p. 11 and fig. 1.

[9] Pickering, E. C., *Ann. Obs. Harvard Coll., Cambridge, Mass.*, **26**, 1891 (260–286).

[10] Adams, W. S., and van Maanen, A., *Astr. J. Albany, N. Y.*, **27**, 1913, p. 187.

[11] Melotte, P. J., *Mem. R. Astr. Soc., London*, **60**, 1915 (175–186).

[12] Kapteyn, J. C., *Mt. Wilson Contr.*, Nos. 82 and 147, *Astrophys. J., Chicago, Ill.*, **40**, 1914 (43–126), **47**, 1918 (104–133, 146–178, 255–282).

[13] Plummer, H. C., *Mon. Not. R. Astr. Soc., London*, **73**, 1913 (174–191).

[14] Charlier, C. V. L., *Meddelanden Lunds Astr. Obs., Lund*, Series 2, No. 14, 1916 (1–108).

[15] Bailey, S. I., *Ann. Obs. Harvard Coll., Cambridge, Mass.*, **60**, 1908, No. VIII.

[16] Newcomb, S., *Pub. Carnegie Inst., Washington, D. C.*, No. 10, 1904 (1–32).

[17] Shapley, Harlow, *Mt. Wilson Contr.*, No. 157, 1918 (1–26), p. 23.

[18] Barnard, E. E., *Astrophys. J., Chicago, Ill.*, **49**, 1919 (1–23).

A COMPARISON OF CERTAIN ELECTRICAL PROPERTIES OF ORDINARY AND URANIUM LEAD

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A comparison of the physical properties of chemical isotopes is of significance because of the light it may throw on the corresponding mechanisms. Comparisons of the properties of ordinary and uranium lead have hitherto been made with respect to the atomic volume,[1] thermoelectric quality,[2] and emission spectra.[3] No differences have been detected, except possibly a very slight shift in one of the spectrum lines. It is not to be expected that large differences exist with regard to other physical properties, but nevertheless a verification by direct experiment is not without interest.

Through the kindness of Prof. T. W. Richards there was made available for me 20 grams of lead of radio-active origin on which he has already published chemical data,[4] and also a similar quantity of puri-